THE MORPHOLOGY OF CERTAIN SPIROCHAETES OF MAN AND OTHER ANIMALS

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I. INTRODUCTION

ON THE MEASUREMENT OF THE LENGTHS OF SPIROCHAETES

It has been recognised for many years that it is extremely difficult to distinguish the smaller spirochaetes by morphological characters. Some authors have gone so far as to assert that 'morphology does not constitute a valid test of species,' and there are a great number of references in the literature to the variations of these organisms.

The discovery of the fact that spirochaetes can be cultivated, although it has placed additional means of identification in the hands of the protozoologist, has not disposed of the difficulty, for the technique is often difficult and laborious, and not all spirochaetes can be grown in artificial media. For diagnostic purposes a morphological criterion is still urgently needed.

There is as a rule nothing distinctive about the movements of the

smaller spirochaetes. All those that I have examined have exhibited at some time or under some circumstances all the types of motion considered characteristic of these organisms. But as the movements vary with the size and condition of the individual spirochaetes, the length of time they have been removed from the body, the temperature, the chemical composition of the fluid in which they are immersed, and other circumstances, they could never be of much value in classification.

Staining reactions are equally unreliable, as they are inconstant, and in the same organism can be made to vary by changing the composition of the medium even very slightly. The structural characters that can be made out in such small parasites are not of much assistance either, since the majority have more or less sharp ends, delicate sinuous bodies which may or may not show some indications of a membrane, and which are sometimes banded by chromatin rodlets and sometimes contain coccoid granules. A decided tendency to form tangles such as occur at the crisis of the diseases caused by some blood spirochaetes, and a definite intracellular phase when it occurs, may, however, be of some assistance. The methods of division, whether longitudinal or transverse, cannot be relied upon, since in many species both occur either simultaneously or under different conditions of growth.

Much importance was at one time attributed to the number and the size of the waves into which the body was bent, but it is now known that these are subject to great variation, depending on a number of factors, such as the size and thickness of the individual organism, the nature and rapidity of its movements, the reaction of the medium, and so forth.

The thickness of spirochaetes also varies considerably in different individuals of the same species, and is very difficult to measure accurately. In the living organism it can only be guessed, and in permanent preparations it varies to some extent with the fixative and the stain employed.

Length is perhaps the morphological character which promises to be of greatest assistance in identification, notwithstanding the fact that considerable variations are known to occur. The length of a species of spirochaete is usually stated as ranging from a minimum to a maximum, but this is unsatisfactory and often actually

misleading, since it affords no means of distinguishing organisms of approximately the same size, and gives no indication of the most common form of the parasite. As I have pointed out elsewhere, this method should logically include the minutest spirochaete just developing out of a coccoid granule and the longest multiple form found under any conditions.

A more reliable and more helpful method of ascertaining the length would be, I believe, to draw with the aid of a camera lucida a large number of the spirochaetes taken as they came, to measure the drawings either by the tangent line or compass method, and to plot the lengths as a curve. As a rule, it would be sufficient to measure thus two or three hundred individuals, but occasionally it might be necessary to draw a larger number taken at regular intervals during the course of the infection. This method would be similar to that adopted in the case of trypanosomes.

In the case of the spirochaetes described briefly in the ensuing pages, this method of determining the length of the organisms has been adopted, and I have employed the same method in the cases of two other spirochaetes described elsewhere (see Table I). The method shows, I think, that although considerable variations do occur, the great majority of the spirochaetes of the same species measure within a few microns of each other in length. The measurements, according to length, may be grouped in the following manner. First there come a few very short forms, which are probably either abnormally small individuals or, in the case of spirochaetes possessing an intracellular phase, immature specimens that have been prematurely freed in the process of making the films. Then there come the normal single spirochaetes which form the dome of the curve and extend over a range of three or four microns. In this group are included all forms, from the recently separated daughter spirochaetes to the fully developed single individuals. This is, in my opinion, the characteristic length of the organism. Next come the pre-division forms and the forms already differentiated into two daughter spirochaetes, united end to end by a delicate filament; and at this point on the curve a small subsidiary crest or halt in the descent may be observed, due to the overlapping in length of large single and small double forms. Finally there come the abnormally long individuals, including hypertrophic specimens,

TABLE I.—The distribution according to lengths, by percentages, of certain spirochaetes of Man and other animals.

Habitat	Number measured	Lengths in Microns by Percentages																				Range in microns
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Over 20	
Throat—human, *S. buccopharyngei*	250	...	...	0·4	1·2	7·2	**14·0**	**18·0**	**19·6**	**13·2**	7·2	6·8	5·2	2·0	2·0	1·6	1·2	...	0·4	...	...	...	3—18
Gums—human, pyorrhoea alveolaris	200	...	...	1·0	4·5	8·5	**14·5**	**18·0**	**18·5**	**11·0**	9·0	5·5	4·5	3·0	1·0	0·5	...	0·5	...	...	...	...	3—17
Urethra—human, *S. urethrae*	300	...	...	...	...	0·7	1·7	5·3	**12·3**	**14·3**	**17·0**	**12·0**	9·3	5·3	6·3	6·0	4·7	2·7	1·3	0·7	0·3	...	5—20
Vagina—human, *S. vaginalis*	100	...	...	...	1·0	2·0	9.0	**19·0**	**15·0**	**15·0**	**14·0**	5·0	5·0	4·0	4·0	5·0	...	1·0	...	...	1·0	...	4—20
Bladder—human	200	...	1·0	**14·5**	**19·5**	**10·5**	3·0	3·0	4·0	5·5	6·0	3·0	2·0	3·5	2·0	2·0	2·5	...	0·5	0·5	1·5	15·5	2—66
Faeces—human, *S.eurygyrata*	200	...	1·0	**19·0**	**28·5**	**27·5**	**15·5**	5·0	2·0	1·0	...	0·5	...	...	...	...	...	...	...	...	...	...	2—11
Faeces—monkey (after death)	100	...	...	3·0	**20·0**	**32·0**	**26·0**	**16·0**	2·0	1·0	...	...	...	...	...	...	...	...	...	...	...	...	3—9
Faeces—cat (after death) ...	100	...	...	3·0	**13·0**	**33·0**	**23·0**	**17·0**	7·0	2·0	1·0	1·0	...	...	...	...	...	...	...	...	...	...	3—11
Faeces—rat	200	...	3·0	**14·0**	**18·5**	**23·5**	**24·0**	9·5	4·5	0·5	2·0	0·5	...	...	...	...	...	...	...	...	...	...	2—11
Faeces—sheep, cattle, goats, pigs	25 from each	...	...	**17·0**	**23·0**	**27·0**	**17·0**	9·0	4·0	2·0	1·0	...	...	...	...	...	...	...	...	...	...	...	3—10
Faeces—dog, *S. canis* ...	200	2·0	**45·5**	**35·5**	**14·0**	3·0	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1—5

unusually large dividing forms, incompletely divided organisms, and the multiple forms not infrequently met with in some cases.

Besides giving a clear idea of the natural size of the organism, this method of plotting the measurements of length may assist in the recognition of mixed infections. When but a single species is present the curve rises rapidly to a crest and rapidly declines, and a short range of three or four microns includes the majority of the individuals. In the case of a mixed infection the curve both rises and falls more gradually, and the range of measurements including the majority of the organisms, is longer. As an illustration of this difference in the form of the curve, the measurements of two hundred spirochaetes from human faeces, *S. eurygyrata*, and a similar number from the human throat are plotted by percentages as curves separately, and combined so as to represent a mixed infection with these two organisms in equal proportions (see Table II and Chart I).

In each of the separate curves there is a well-marked crest, and the commonest lengths, namely, those including 10 per cent. of the organisms, or more, cover a range of 4 microns, from 3μ to 6μ in the case of *S. eurygyrata*, and from 6μ to 9μ in the case of the throat spirochaete; but in the combined curve the crest is less marked, and the commonest lengths extend over a greater range.

Table II.—The distribution according to length of 200 spirochaetes from human faeces, and a similar number from a human throat.

Site of infection	Lengths in Microns																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Faeces ...	2	38	57	55	31	10	4	2	...	1	...	...	...	...	...	...	...
Throat ...	...	1	3	15	29	36	40	26	15	13	12	3	3	2	1	...	1
Totals ...	2	39	60	70	60	46	44	28	15	14	12	3	3	2	1	...	1
Percentages ...	0·5	9·75	15·0	17·5	15·0	11·5	11·0	7·0	3·75	3·5	3·0	0·75	0·75	0·5	0·25	...	0·25

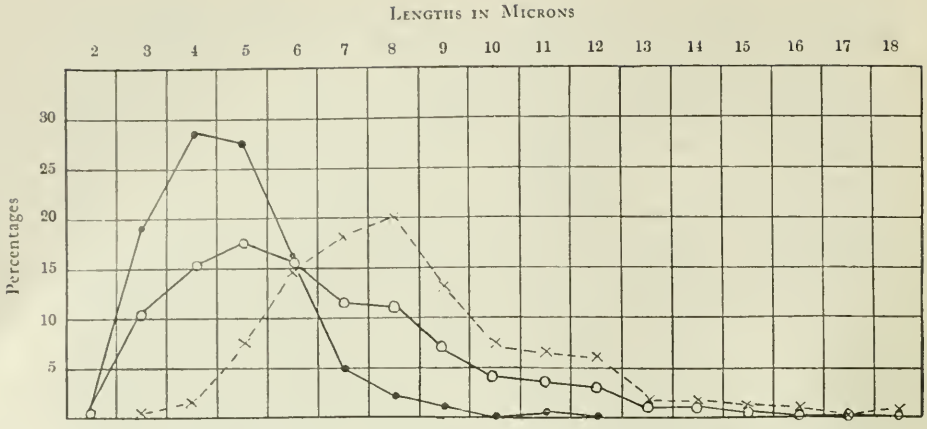

Chart I.—The distribution, by percentages, according to length of spirochaetes from the human faeces (● ——●——) and throat (× – – – × – – –), and the curve representing a mixed infection with these two organisms in equal proportions (o——o——).

II. A SPIROCHAETE FOUND IN THE VAGINA

It might be expected that spirochaetes would be frequently found in the vagina since the conditions in this locality must often be favourable for their growth. So far as I am able to ascertain, this is not the case, and with the exception of *Spirochaeta aboriginalis* associated with ulcerative granuloma of the pudenda, and *Spirochaeta phagedenis* found in an indurated and ulcerated swelling of the labium, no organisms of this nature have been described from the vagina. It may, therefore, be of interest to record briefly a case of vaginitis, which has recently come under my notice, in the discharge from which spirochaetes were present, which, so far as could be judged, appeared to be the cause of the disease.

CLINICAL CONDITION AND THE MATERIALS EXAMINED

The patient was a girl, seventeen years of age, a native of Lagos, who came to the Accra Hospital complaining of discharge from the vagina. On examination, the surface of the vagina was found to be slightly red and congested, but there was no ulceration. The discharge was scanty. Three dried smears of this discharge

were sent to the laboratory for examination, and in them a large number of spirochaetes were found, together with some long Gram-positive bacilli and numerous epithelial scales. Unfortunately, the patient had already left the hospital before the specimens were examined, and she did not return for further treatment. The living spirochaetes could not therefore be examined.

MORPHOLOGY OF THE SPIROCHAETES

The morphology of the spirochaetes was studied in the three dried films of the discharge, after staining with Romanowsky (Leishman), gentian violet, and by Gram's method, using fuchsine as the counter stain. The parasites stained well with these reagents, were decolourised by Gram's method, and with Leishman's stain were coloured a purplish tint.

The spirochaetes showed a considerable degree of morphological variation, but always had flexible sinuous bodies, bent into a number of curves or waves.

The number of waves was very variable, and this was probably due to the nature of the movements of the organisms at the time when they were fixed. Some had practically no coils, or only a few large flexions, giving them a contorted appearance (fig. I, 4-8).

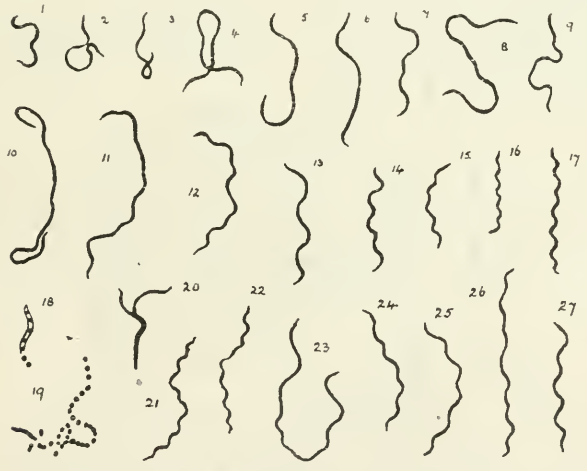

FIG. I.—*Spirochaeta vaginalis*, Macfie. 1-27: various forms found in the vaginal discharge; 18: coccoid bodies escaping from the periplastic sheath; 19: coccoid bodies apparently formed from spirochaetes; 20: a parasite undergoing longitudinal division; 21-23: others undergoing transverse fission. All the figures were drawn with the aid of an Abbé-Zeiss camera lucida at a magnification of 2000 diameters.

These spirochaetes had probably been executing lashing movements and undulatory flexions at the moment of fixation. Others showed a large number of small close waves such as are associated with rapid helicoid movements (fig. I, 14-17). In some the waves were deep, in others they were shallow; and the number varied also in relation to the size and thickness of the organism. No general statement as to the number of waves characteristic of the organism can be made, but sometimes there were as few as two and sometimes as many as nine or ten. The number of coils is probably not important, and, as Fantham (1916) has pointed out, cannot be regarded as a specific character.

The ends of the spirochaetes were tapering, but some were more pointed than others. The organisms were extremely slender, so that it was not possible to measure them exactly, but the majority were about 0·2μ broad. There were, however, considerable variations, some individuals being obviously thicker than others.

The variation in length of the spirochaete was determined by drawing a hundred individuals taken as they came, with the aid of a camera lucida, and measuring them. The shortest spirochaete measured was 4μ, the longest 20μ, and the average length worked out at 9·3μ (see Table I). A better idea of the length characteristic of the organism is, however, obtained by plotting the measurements, as has been done in Chart II. On examining this curve, it is clear that the majority, 63 per cent., of the parasites measured 7μ to 10μ

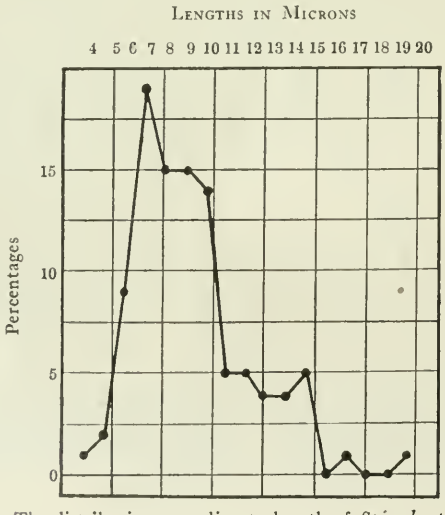

Chart II.—The distribution according to length of *Spirochaeta vaginalis* (Macfie).

in length. Although the number of measurements was small, it is evident from the nature of the curve that only a single species of spirochaete was being dealt with, and one whose length was most commonly 7μ to 10μ; it was therefore considered unnecessary to measure a larger number. The slight secondary crest on the curve at 15μ was no doubt due to the overlapping in length of large single and small double forms.

So far as could be judged from the materials available, division seemed to occur most commonly by the transverse method, organisms compounded of two daughter spirochaetes linked by a delicate filament being frequently seen (fig. I, 21 and 22). A few Y-shaped parasites were, however, present which appeared to represent a stage in longitudinal division (fig. I, 20). The common stem of these forms did not show any signs of being double, and was quite unlike the re-curved forms also occasionally seen in the smears.

The cytoplasm of the majority of the spirochaetes appeared to be homogeneous, but a few showed very beautifully a succession of granules or rodlets at short intervals along their bodies. No vacuoles could be distinguished. Slight indications of a sinuous membrane were seen in one or two specimens only.

Coccoid bodies were seen within some of the spirochaetes, and in others the end of the organism appeared to have disintegrated, liberating the granules (fig. I, 18). A few chains of granules were also seen, the appearance of which suggested that they had been formed in spirochaetes (fig. I, 19). These chains were composed of rounded or oval bodies resembling minute cocci, which, when stained by Gram's method, were decolourised.

A few of the epithelial scales found in the discharge contained spirochaetes, generally only one or two, but occasionally more. A part of one such scale is figured showing five spirochaetes and two bacteria (see fig. II). The parasites seen within the scales were

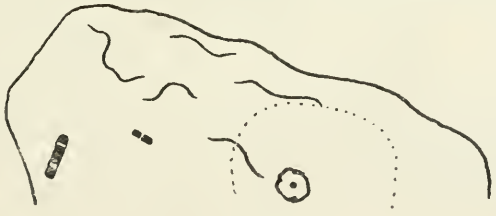

Fig. II.—Portion of an epithelial scale from the discharge in which five spirochaetes and two bacteria are shown. Drawn with the aid of an Abbé-Zeiss camera lucida at a magnification of 2000 diameters.

generally small and of a simple form, and suggested the possibility that this organism passes through an intracellular phase similar to that which I have described as occurring in *S. urethrae*. Unfortunately the materials available were insufficient, and the infection at the time of examination was not heavy enough to have enabled me to follow out such a phase through all its stages, even supposing that it did occur.

THE IDENTITY OF THE SPIROCHAETES

In ulcerative granuloma of the pudenda a spirochaete, *S. aboriginalis*, has been found which measured about 12μ in length, ranging from forms a few microns to others 18μ or 20μ long, and had irregular waves. Another spirochaete, *S. phagedenis*, was found by Noguchi in an ulcerated swelling of the labium, and this organism measured from 4μ to 30μ in length. The patient from whom the spirochaete described above was obtained suffered from a slight vaginitis, but had no ulcerative lesions, and even apart from this the parasite she harboured differed in dimensions from both *S. aboriginalis* and *S. phagedenis*.

Treponema pallidum might under certain circumstances be found in the vagina even at a time when no specific lesions were visible. The spirochaetes found in this case sometimes had a membrane and the coils were not fixed, so that this organism can be excluded. *Spirochaeta refringens* or *S. balanitidis* might be introduced into the vagina, and if the conditions were favourable might continue to multiply there. These two organisms are considered by some authorities to be the same, and as they are generally described as measuring 8μ to 12μ in length, they are probably distinct from the spirochaete found in this case. Some writers state that *S. refringens* measures 20μ to 35μ in length.

The ill-defined *S. vincenti* might conceivably invade the vagina, but this species is also a somewhat larger organism, measuring as a rule 12μ to 25μ in length, and sometimes attaining 40μ. *S. urethrae*, the organism I described recently from a case of urethritis, measures most commonly 8μ to 12μ in length, and is a slightly larger parasite.

Spirochaetes from the intestine might find their way into the

vagina. A number of different species have been described as occurring in the human intestine, such as *S. hachaizae*, *S. eurygyrata*, *S. stenogyrata*, and others, but Fantham (1916) has recently shown that all these parasites are morphological variations of a single species, *S. eurygyrata* Werner emend. Fantham. This organism he has defined as having tapering ends, and measuring 3μ to 15μ in length, and about 0·25μ in breadth. *S. eurygyrata* is therefore a much smaller organism than the one found in the vagina of this native girl.

It must be concluded that the vaginal spirochaete described above is distinct from all these organisms, and I therefore propose for it the name *Spirochaeta vaginalis*.

CONCLUSIONS

1. Spirochaetes were found in the discharge from a mild case of vaginitis in a native woman which it is believed were the causal agent of the disease.

2. These organisms, which had pointed ends, were most commonly 7μ to 10μ in length, but of a hundred individuals measured the longest was 20μ and the shortest 4μ long. They were about 0·2μ in breadth, and might show any number of waves from two to ten.

3. The name *Spirochaeta vaginalis* is proposed for this parasite.

III. A SPIROCHAETE FOUND INHABITING THE BLADDER

In a case of chronic cystitis large numbers of spirochaetes were found in the urine, which, although they were probably not the cause of the disease, are of interest because of the extraordinary degree of morphological variation they showed.

The patient, a native man, 30 years of age, stated that three years ago he contracted gonorrhoea, that as a result of this infection an obstruction formed in his urethra causing the penis to swell greatly, and eventually, about a year ago, to burst. He came to hospital in order to undergo an operation because he was passing his

urine through two fistulae, one on either side of the penis, about two inches from its end. The urethra was completely occluded by a stricture just in front of these fistulae. The patient complained also of pain over the region of the bladder, and there was a little white discharge from the fistulae.

The urine was brown in colour, turbid, strongly alkaline, and had a specific gravity of 1015. Albumen, pus, and a trace of blood were present, but no sugar. On standing, an abundant sediment collected at the bottom of the glass, which was composed mainly of triple phosphates crystals, but contained also a large number of pus cells, a few red blood corpuscles, epithelial scales, yeast cells, bacteria, and a considerable number of spirochaetes. The bacteria were countless, and included staphylococci, streptococci, motile and non-motile Gram-negative and Gram-positive bacilli. No casts were found.

The pus taken from the urethral fistulae contained the usual polymorphonuclear cells, epithelial scales, staphylococci, and Gram-negative and Gram-positive bacilli. With the exception of a few clumps of bacteria, there were, however, very few organisms present, and it was only after careful search that any spirochaetes were found. It was evident, therefore, that the main infection was in the bladder, and that the spirochaetes were living chiefly, if not solely, in the urine. No gonococci were found in either the urinary deposit or the discharge from the fistulae.

From the clinical aspect, the case was therefore one of chronic cystitis secondary to a urethral infection, and there was no reason to regard the spirochaetes found as anything more than saprophytic organisms living and multiplying in the pathological urine in company with the hosts of bacteria.

THE CHARACTERISTICS OF THE LIVING SPIROCHAETES

On examining the urine two apparently distinct types of spirochaetes were seen, both occurring in considerable numbers.

The first type was a small, slender organism that moved rapidly about the field of the microscope. Its movements were mainly composed of undulatory flexions and corkscrew motions, but sometimes the organism showed active lashing movements.

Progression might be in either direction, and a reversal of the direction was sometimes witnessed. The body of the spirochaete was slender, the ends appeared to be pointed, granules in the cytoplasm although sometimes present were not conspicuous, and there were usually relatively few waves. This type closely resembled the *S. eurygyrata* so commonly found in the faeces in this country.

The second type was a long, sluggish organism. Many of the spirochaetes of this type were quite motionless, and those that were active showed only slow undulant and helicoid movements. Progression was deliberate, but might take place in either direction, and a reversal was seen several times. These organisms were decidedly broader than those of the first type, their ends were usually quite blunt, and their bodies were conspicuously granular and often beautifully banded. The relatively enormous length of some of these spirochaetes was perhaps their most remarkable feature. As a rule, the body was bent into a large number of waves, sometimes as many as twenty-six, and this was just as noticeable in the immobile individuals as in those exhibiting movements. Many of these organisms looked as if they were made up of two or more parts, but although a number of them were watched carefully, division was never observed. It should perhaps be stated at once that the possibility that these forms might be bacterial was not overlooked, but that after careful consideration it was dismissed.

Two more dissimilar organisms than these could hardly be imagined; the one short and most active, the other very long and very sluggish.

MORPHOLOGY

The spirochaetes of both types showed a high degree of morphological variations. The organisms of the first type (fig. III, 1-28) had slender flexible bodies bent into a number of waves or coils. The waves were generally two to five in number, but some of the spirochaetes were simply bow-shaped and others had more than five. The ends of the organism were tapering. The cytoplasm of the body was usually homogeneous, but some of the larger individuals showed transverse chromatin bands or rods, and others contained granules. A membrane was never seen distinctly, but some specimens appeared to have a band partly filling up the trough

of some of their waves, which may have been this structure. The spirochaetes were very slender, so that it was difficult to measure them, but their thickness was about 0·25 μ. Some individuals were

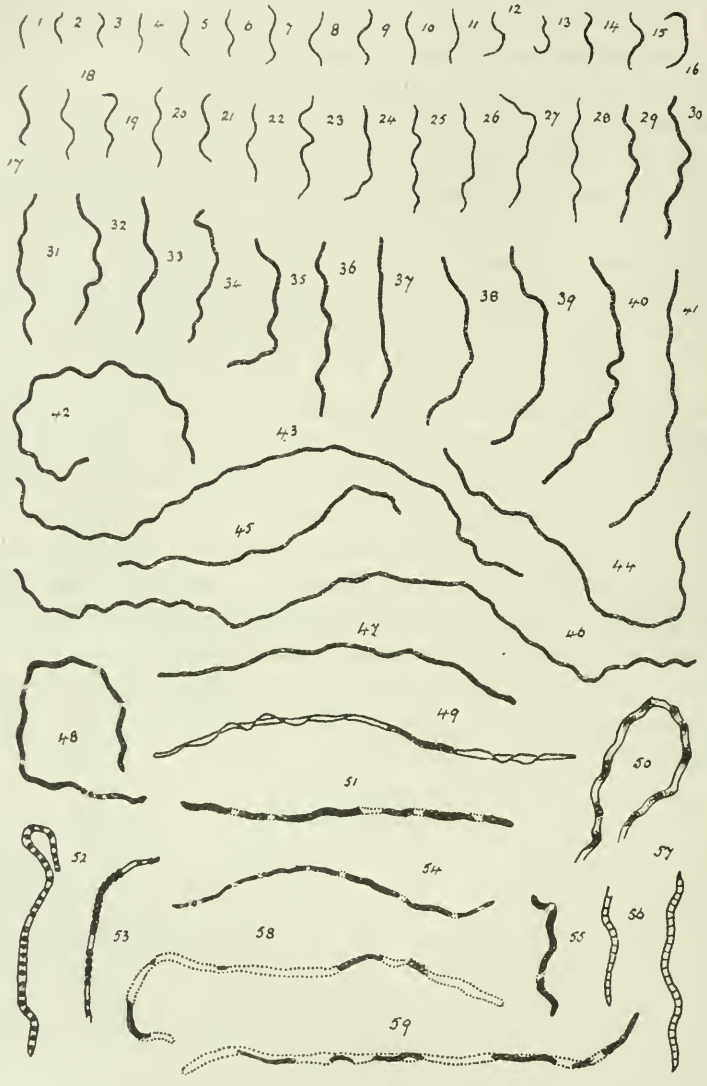

Fig. III.—Various forms of spirochaetes found in the urine in a case of chronic cystitis. All the drawings were made with the aid of an Abbé-Zeiss camera lucida at a magnification of 2000 diameters; the thickness of the organisms, however, is only approximately indicated, and in 48-59 it has been exaggerated somewhat in order to show the structure. 50, 53, and 56 show parts of longer spirochaetes.

decidedly stouter than others. When stained by Leishman's method the organisms were usually coloured purplish, but this is not really a matter of any importance, as the tint assumed by spirochaetes can be made to vary by changing the chemical constituents of the fluid in which they are living.

A typical spirochaete of the second type was a much coarser organism, and there was the greatest variation in size and shape and structure (fig. III, 29-57). The body was bent into waves, which were sometimes well marked and at other times indistinct, and also long undulations on which the waves were superimposed. Small specimens might show only three or four waves, but large ones, as has already been mentioned, might have as many as twenty-six. The ends of the spirochaetes were generally distinctly blunt, but they often tapered somewhat, but were never so sharply pointed as those of the first type. A periplastic membrane was sometimes visible, but reference will be made to this again later. The organisms were broader than those of the first type, and measured usually 0·4μ in thickness. The breadth did not sensibly increase with the length of the body, the extremely long individuals being just about the same thickness as the shorter ones. There were, however, considerable variations, and some long specimens were no broader than the spirochaetes of the first type. The structure of the cytoplasm varied a great deal. Some of the spirochaetes, and these were generally the smaller ones, appeared to be almost homogeneous; but more usually the body stained irregularly. Chromatin bars or rodlets at short intervals all along the body were sometimes seen most clearly (fig. III, 56 and 57), and other organisms seemed to have broken up into rounded or oval granules within the periplastic sheath (fig. III, 52). Most of the larger individuals, however, were composed of a sheath in which irregularly shaped segments of various sizes were enclosed. When stained by Leishman's method the sheath was coloured grey or dull blue, and the granules a chromatin tint. In some specimens the granules appeared as rather diffuse collections of chromatic material, more concentrated in the centre, and at the periphery merging gradually into the general cytoplasm (fig. III, 50); in others the granules were shaped like narrow rods, which when carefully examined were seen to be beaded (fig. III, 53); but most commonly the periplastic sheath contained a

larger or smaller number of homogeneous bodies, rounded, bacilliform, or shaped like spirilla (fig. III, 48, 51, 54). From some of the spirochaetes nearly all these bodies seemed to have vanished, leaving an empty periplastic sheath (fig. III, 49 and 58). It was in these specimens that the appearance of a membrane was most distinct, but the effect may have been due to the irregular twisting of the sheath or to damage done at the time when the enclosed bodies escaped (fig. III, 49).

In addition to these two distinct types of the organism, there were a number of intermediate forms which bridged the gap both in length and breadth.

As regards the length of the spirochaetes found in this case, two hundred individuals, taken as they came, were drawn with the aid of a camera lucida and measured. The shortest specimen measured 2μ, and the longest 66μ. The latter measurement was not the maximum, as elsewhere in the films even longer individuals were found. It was at once obvious that to take the average of such measurements would be highly misleading, and, as a matter of fact, this average was 11μ, a length to which only 3 per cent. of the spirochaetes belonged. The measurements were, therefore, distributed according to their lengths in microns, and it was hoped that in this way some indication might be obtained as to the nature of the infection. As the curve formed by these measurements (see Chart III) appeared to be satisfactory, it was considered unnecessary to measure a larger number of the organisms.

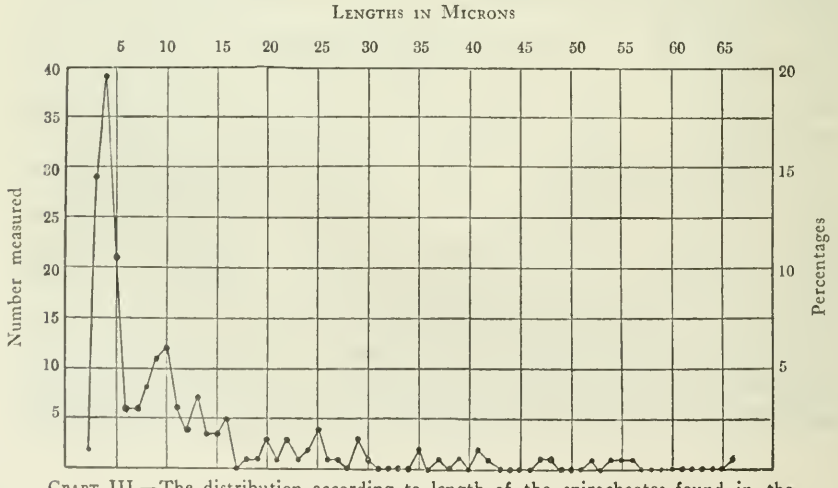

Chart III.—The distribution according to length of the spirochaetes found in the urine in a case of chronic cystitis.

An examination of this curve is, I think, instructive. It shows in the first place a most pronounced crest, which proves, I believe, that the spirochaetes all belonged to a single species. This species measured from 2μ to 16μ in length, and one must conclude that all the longer specimens were multiple forms, a view that is supported by their morphology. The greatest number of the spirochaetes, nearly 20 per cent., measured 4μ, and 44·5 per cent. of them were within 3μ of each other in length, between 3μ and 5μ. This is the most characteristic length of the species. The curve shows a secondary crest at 9μ to 10μ, indicating the lengths at which large single and small double forms overlap. The length of the spirochaete may be said, therefore, to vary from 2μ to about 10μ, but to be most commonly 3μ to 5μ long.

THE IDENTIFICATION OF THE SPIROCHAETE

The curve formed by distributing the measurements of length of the two hundred spirochaetes drawn indicates that the small type of the organism was the true form of the parasite; and this organism appeared to correspond with the descriptions of *S. eurygyrata*.

S. eurygyrata was originally described by Werner (1909) from specimens found in his own stools, and was stated to be 'a wide wound form' measuring from 4·6μ to 7·3μ in length. The same author found in the same materials 'a narrow wound form' varying in length from 3·5μ to 6·1μ, which he considered to be a distinct species, and which he named *S. stenogyrata*. Fantham (1916) has recently studied the spirochaetes occurring in human faeces, and has come to the conclusion that both the parasites described by Werner, and several others briefly referred to by earlier writers, are morphological variations of the same species. *S. eurygyrata*, Werner emend. Fantham, is defined as an organism which has pointed ends, measures from 3μ to 15μ in length, and is about 0·25μ in breadth. These measurements are almost exactly those which I determined as being characteristic of the spirochaete found in the urine of the case described; and a comparison of the morphology of the organism I have described with that of *S. eurygyrata* given by Fantham can leave no doubt as to the identity of the two organisms.

The patient whose case I have recorded was suffering from a

chronic cystitis, and the history of his illness was such as to make it highly probable that organisms from the rectum might have invaded the bladder, and it is probable that the spirochaetes found multiplying in the urine had originally been derived from this source.

THE SIGNIFICANCE OF THE LONG TYPE OF SPIROCHAETE

The curve shown in Chart III suggests that the long type of the spirochaete was a multiple form, since those measured were found to be distributed irregularly over a wide range of lengths.

In the urine of the patient, as is usual in chronic cystitis, there were a great number of epithelial scales, but neither in living specimens nor in fixed and stained preparations were any spirochaetes seen in these cells. The spirochaetes, in fact, appeared to be saprophytes, and the urine in the bladder, so far as could be ascertained, was just a culture of these organisms in symbiosis with a varied bacterial flora. The long type of the spirochaete was probably comparable to the multiple forms frequently found in cultures of these organisms.

The smallest individuals of the long type were perhaps hypertrophic, as they sometimes had almost homogeneous cytoplasm or showed a banding of their bodies by chromatic rods (fig. III, 55-57). Slightly larger specimens were frequently seen to contain coccoid bodies, often arranged in rather irregular groups (fig. III, 53). The very long organisms, however, were almost always composed of a delicate periplastic sheath, within which a number of deeply stained bodies were enclosed (fig. III, 51, 54). These bodies were homogeneous in structure and varied in size and shape, some being rounded or oval, some bacilliform, and others bent or curved like spirilla. The latter bodies resembled in shape and size the small free forms of *S. eurygyrata*, but differed from them in having blunter ends. The appearance of these long spirochaetes was such as might be expected to result if the coccoid bodies, instead of being liberated from the organism, were to develop within the periplastic sheath. It is possible that some of the very long individuals had been formed in this manner, but others were probably true multiple forms in which transverse division was incomplete, leaving the daughter spirochaetes still attached end to end by delicate filaments. I do not think all

the forms were alike, and the difference in the method of formation that I have suggested might explain this, and also account for the variations observed in thickness, those forms in which there was a definite periplastic sheath enclosing the separate bodies being the broader.

If I am correct in interpreting all these dissimilar forms as being morphological variations of a single species, *S. eurygyrata*, their occurrence in this patient must, I think, be attributed to the fact that the spirochaetes were multiplying in the urine instead of in the intestinal contents, the unusual nature of the medium determining the production of unusual forms of the organism.

IV. A SPIROCHAETE FOUND IN THE THROAT IN A CASE OF CHRONIC PHARYNGITIS

Some points of interest were raised by a study of the morphology of a spirochaete found in the human throat.

The patient, a native of Accra, a man of about thirty years of age and by employment a cook, applied for treatment at the hospital in January, 1916, complaining of his throat. He stated that his illness had commenced about a year previously with a sore throat, that he had suffered from the same complaint off and on ever since, and that during the last month he had been greatly troubled with a cough, especially at night time. On admission no very definite signs were detected in the chest, but the breath sounds at both apices were harsh, there was slight dullness over the base of the left lung, and a few moist sounds at the base of the right lung. The throat, however, was slightly inflamed and appeared to be in a chronic catarrhal condition, but there was no ulceration. The sputum, which was copious and watery, seemed to come entirely from the throat. In it there were a few red corpuscles, a number of vacuolated polymorphonuclear leucocytes, and epithelial scales. No tubercle bacilli could be found, but fusiform bacilli and very large numbers of spirochaetes were present.

The materials examined were the sputum, which appeared to come entirely from the throat, and the muco-purulent discharge obtained directly from the throat by means of a sterile swab. The

patient's mouth and teeth were first thoroughly cleansed by means of a stiff brush, the mouth and throat were then washed with carbolic lotion (1 in 40), and finally rinsed out with sterilised water. The sputum and swabs were examined immediately after they left the body, and both were found to contain the same organisms in approximately the same numbers.

Under treatment the patient improved considerably, and his general health became much better. The chronic catarrhal condition of the throat, however, proved refractory. When last seen, in August, 1916, his voice was still very husky, his throat was slightly red and covered by a small amount of muco-purulent discharge, and he was still expectorating a considerable quantity of fluid. No spirochaetes could be found in the sputum at this date.

MORPHOLOGY OF THE SPIROCHAETE

The spirochaetes when alive were generally active, and their movements varied considerably, but did not show any characters of specific importance. They stained readily with any of the usual reagents, and were decolourised by Gram's method. Their bodies were flexible and sinuous, somewhat thicker in the middle, and tapering at the ends sometimes to sharp points, sometimes to slightly blunter extremities (fig. IV, 1-48). Some of the spirochaetes were loosely, others closely coiled. The actual number of waves into which their bodies were bent varied greatly, some showing only one or two, others six or more, but the majority had perhaps three or four. The number of waves varied with the length and the thickness of the organism, and also with the nature of its movements. The periplast of some of the spirochaetes was extended laterally into a definite sinuous membrane or crest, or terminally into a delicate appendage. Both these structures were, however, impossible to distinguish in most of the organisms.

Multiplication appeared to occur by both longitudinal and transverse division. Spirochaetes composed of two daughter organisms, linked end to end by a delicate filament, were not uncommon (fig. IV, 46-48); but the Y-forms that suggested longitudinal division were rare (fig. IV, 45). Although epithelial scales were abundant, both in the sputum and in smears taken directly

from the throat, no indications of an intracellular phase were observed. The occurrence of a few very small individuals, measuring only 3μ or 4μ in length (see Table III), suggested, however, that such a phase might occur.

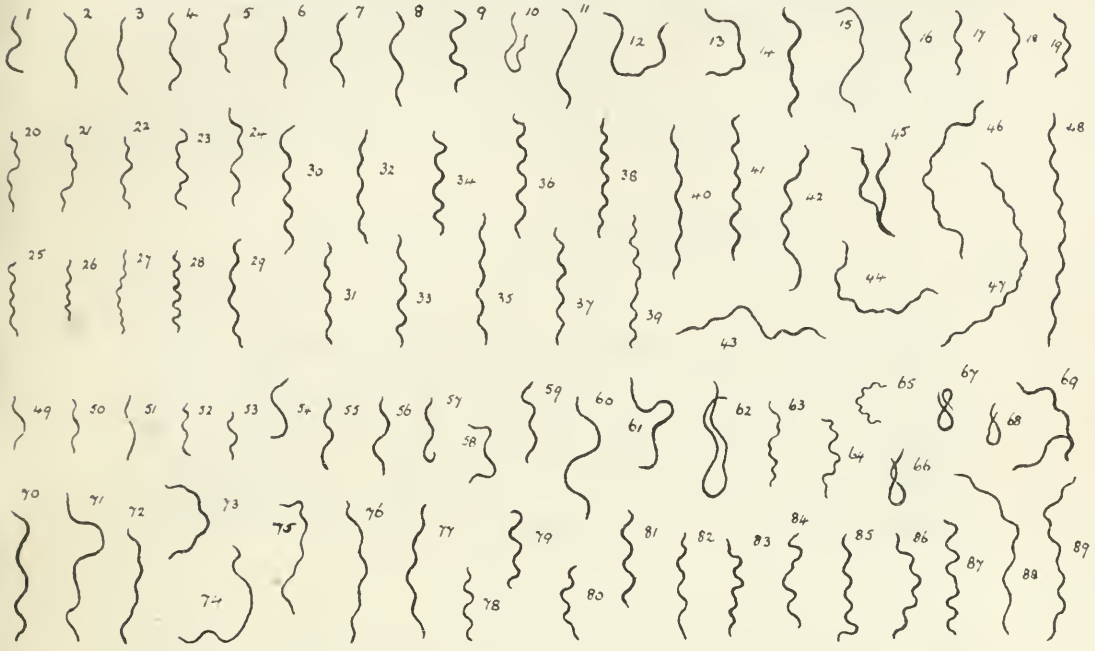

Fig. IV.—1-48 : spirochaetes from the throat of a case of chronic pharyngitis; 49-89 : spirochaetes from the gums of a case of pyorrhoea alveolaris. All the figures were drawn with the aid of an Abbé-Zeiss camera lucida at a magnification of 2000 diameters; the thickness of the spirochaetes is, however, only approximately indicated.

The cytoplasm of the majority of the spirochaetes appeared to be homogeneous and non-vacuolated, but a number of them showed a banding of the body by chromatin rodlets, and not a few contained coccoid bodies.

Tangles were occasionally seen in the stained preparations, and also recurved forms.

The spirochaetes varied in breadth according to the stain employed, and on account of their activity could not be measured when alive. Even in the same preparation, however, considerable variations occurred, some individuals being twice as thick as others,

but the breadth did not appear to bear any direct relationship to the length. Accurate measurements were in any case almost impossible owing to the slenderness of the organisms, but the majority probably measured about 0·25 μ.

TABLE III.—The distribution according to lengths of the spirochaetes from (*a*) the throat in a case of chronic pharyngitis, and (*b*) the pus from the gums in a case of pyorrhoea alveolaris.

Habitat	Number measured	Lengths, by Percentages, in Microns															
		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Throat ...	250	0·4	1·2	7·2	14·0	18·0	19·6	13·2	7·2	6·8	5·2	2·0	2·0	1·6	1·2	...	0·4
Gums	200	1·0	4·5	8·5	14·5	18·0	18·5	11·0	9·0	5·5	4·5	3·0	1·0	0·5	...	0·5	...

The length of the organism was determined by drawing with the aid of a camera lucida and measuring 250 individuals taken as they came (see Table III). The shortest of these measured 3 μ, the longest 18 μ, and the average worked out at 8·4 μ. A better idea of the true length of the spirochaetes is obtained by plotting the measurements as a curve (see Chart IV), and it is then seen that

CHART IV.—The distribution according to length of 250 spirochaetes from the throat of a native at Accra.

64·8 per cent. of the organisms measured within 4μ of each other, in length between 6μ and 9μ. This curve is of the form typical of the variations of a single organism, and proves clearly, I believe, that all the spirochaetes found in this patient were of the same species. Both pre-division forms and forms made up of two daughter spirochaetes still attached were included in these measurements, the latter measuring usually 13μ to 16μ, and their components 6μ to 8μ. The slight subsidiary crest, or rather halt in the descent of the curve, at 11μ to 12μ was probably due to the overlapping in length of long single and small double forms.

THE IDENTITY OF THE SPIROCHAETE

In a throat condition such as that from which this patient suffered, the spirochaetes that might be expected to occur most probably are *S. vincenti*, *S. bronchialis*, *S. dentium*, and *S. buccalis*. Certain other species have been described, such as *S. gracilis*, *S. microgyrata*, and *S. media*, which, however, are generally considered to be referable to one or other of the species previously mentioned; and several treponemas have been named, such as *T. intermedium*, *T. macrodentium*, *T. microdentium* and *T. mucosum*, which may be excluded, as the organism under discussion sometimes had a so-called membrane and its coils were variable. For the same reasons *T. pallidum* must be excluded.

Spirochaeta vincenti, which characteristically occurs in the throat, is described as having a flexible, irregularly coiled body, tapering at both ends, and is found associated with fusiform bacilli. In these respects it resembles the organism in the case described above. *S. vincenti* is, however, stated by some authors to be sluggish; Plaut has described a euglenoid type of movement; and others, such as Goadby (1916), consider it to be non-motile. As regards measurements, Bosanquet gives the usual length as 10μ, but states that Mackie records specimens measuring as much as 40μ; Castellani and Chalmers give 12μ to 25μ; and Fantham (1915) mentions some measurements ranging from 9μ to 23μ made by him from the drawings published by Thomson and Mühlens, but points out that little is known of the range of morphological variation of this species. Without going into further details, it is evident,

I think, that the active organism, measuring most commonly 6μ to 9μ, that I have described cannot have been *S. vincenti*.

With regard to *S. bronchialis*, a parasite originally described by Castellani, nothing definite can be said, as more recently it has been admitted by this author with Chalmers that the name 'probably includes several varieties of spirochaetes.' From my own observations at Accra (1915), I concluded that the organism found in cases of bronchial spirochaetosis averaged 8μ to 9μ in length, and was indistinguishable from a mouth spirochaete. Fantham has studied the morphology of *S. bronchialis* more recently, and states that its length may range from 5μ to 27μ. He considers that it is distinct from the spirochaetes occurring in the mouth, but his reasons are not very convincing, and the question cannot be regarded as settled.

The two common mouth spirochaetes, *S. dentium* and *S. buccalis*, might be expected to occur in lesions of the throat. These organisms have recently been studied by Fantham (1915). *S. dentium* is said to measure from 4μ to 10μ in length, and from 0·3μ to 0·6μ in breadth, to have a number of well-marked regular coils, and to resemble *T. pallidum* in general appearance, but to be thicker, shorter, and rather less sharply coiled. Mühlens figures chromatin granules in this organism, but Fantham states that it is so small that few structural details can be made out, and that in consequence 'it might be placed by some authorities in the genus *Treponema*.'

S. buccalis is a larger, thicker organism, resembling *S. vincenti*. It is said by some to be active (Mühlens), by others to be sluggish (Goadby); its body is loosely coiled; its extremities are 'somewhat rounded or bluntly acuminate' (Fantham); it has terminal periplastic appendages, and a membrane or crest may be present (Hoffmann). Its length is variously stated as 12μ to 20μ (Hartmann and Mühlens), and 9μ to 22μ (Fantham), and it is said to be 0·5μ to 1μ broad.

The spirochaete that I have described differed from both these species in some particulars, and resembled them in others. It was longer than *S. dentium*, sometimes had a membrane and terminal periplastic appendages, and was not always closely coiled. It was shorter than *S. buccalis*, its ends were not as a rule blunt, and its coils were not always loose.

Intermediate forms which might be considered to connect *S. dentium* and *S. buccalis* are known to occur in the mouth, and to these Dobell has given the name *T. intermedium*. It is possible, however, that *S. dentium* and *S. buccalis* may be morphological variations of a single species. If this were so, the organism would range in length from 4μ to 20μ or 22μ; would be sometimes loosely, sometimes closely coiled; would have pointed or rather blunter ends; would show in some specimens a membrane, terminal periplastic appendages, chromatin rodlets, and coccoid bodies; would generally be active, but sometimes more sluggish; would occur as tangles occasionally; would show signs of multiplication by both longitudinal division and transverse fission; but would not show intracellular stages. This description corresponds almost exactly with that of the spirochaete I have given above.

As I have already pointed out, I believe that the curve of the measurements of length of the spirochaetes from the throat in the case I have described, proves that the infection was not a mixed one, but was with a single species; and from what has just been stated, this organism appears to combine the characters of *S. dentium* and *S. buccalis*. For this parasite I propose the provisional name *Spirochaeta bucco-pharyngei*, although it is possible that later it may have to be merged with *S. dentium* and *S. buccalis*, in which case the name *S. buccalis* will have priority.

In this connexion it may be of interest to record the fact that an apparently identical spirochaete was found in a severe case of pyorrhoea alveolaris in a native man. In the pus that welled up from the sockets of the teeth on pressing over the gums of this patient, both amoebae and spirochaetes were found. The latter organisms were present in myriads, and, so far as their structure was concerned, resembled exactly the spirochaete from the throat described above (fig. IV, 49-89). They were very active when alive, and showed lashing, undulatory, and helicoid movements. Two hundred individuals, taken as they came, were drawn with the aid of a camera lucida, and measured. The longest of these was 17μ, the shortest 3μ, and the average worked out at 7·97μ (see Table III); the majority, 62 per cent., were within four microns of each other in length between 6μ and 9μ. These measurements and the curve of the distribution of the spirochaetes according to length (see

Chart V) so closely resemble those of the throat spirochaete that it must be concluded they were the same. The spirochaetes in the pus from the gums were presumably mouth spirochaetes, and the nature of their variations according to length support the view I have suggested, namely, that *S. buccalis* and *S. dentium* may really be different forms of the same organism.

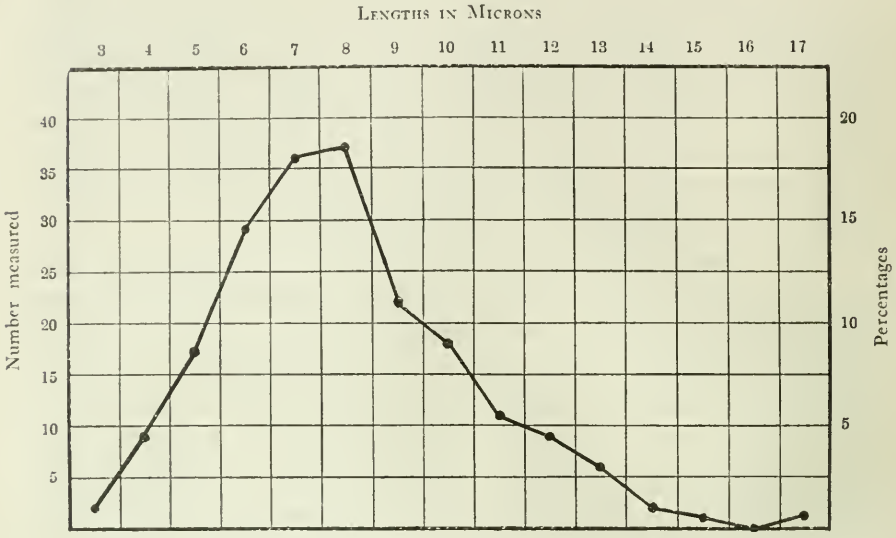

Chart V.—The distribution according to length of 200 spirochaetes from a case of Pyorrhoea alveolaris in a native at Accra.

REFERENCES

Castellani, A., and Chalmers, A. J. (1913). Manual of Tropical Medicine, 2nd Edition, pp. 402 and 1283.

Fantham, H. B. (1915). *Spirochaeta bronchialis*, Castellani, 1907, together with Remarks on the Spirochaetes of the Human Mouth. *Annals of Tropical Medicine and Parasitology*, Vol. IX, pp. 391-411.

Goadby, K. (1916). Ulcerative Stomatitis. *Lancet*, 6 May, pp. 959-961.

Macfie, J. W. S. (1915). Bronchial Spirochaetosis. *Journal of Tropical Medicine and Hygiene*, Vol. XVIII, pp. 63-65.

V. OBSERVATIONS ON THE INTESTINAL SPIROCHAETES OF CERTAIN OF THE LOWER ANIMALS

It is well known that spirochaetes are common in the alimentary canals of animals, but the knowledge regarding them appears to be fragmentary. Until quite recently, even the intestinal spirochaetes found in man had not been thoroughly studied, and with the exception of a few brief references, I am unable to discover in the literature at my disposal any descriptions of the forms found in domestic animals. The indifference hitherto displayed towards these organisms is no doubt due to the fact that most of them appear to be, or are assumed to be, non-pathogenic. They are generally regarded as being saprophytes, and therefore of little account; but it may be worth while considering this attitude a little more closely.

Many of the spirochaetes found on the surfaces of ulcerative lesions are also regarded as being saprophytic, but in some cases there is evidence that the organisms may spread beyond the superficial lesions, and even become blood parasites. Baermann, for example, found *S. refringens* in enlarged glands in a monkey infected with syphilis, and Scherber states that *S. balanitidis* may make its way into the blood-vessels. It is surely not impossible, then, that spirochaetes from the intestinal tract might find their way into the blood stream. In the course of examining blood films from the Accra slaughter-house in 1914, spirochaetes were occasionally found: namely, in four out of 166 cattle, four out of 95 sheep, one out of 94 pigs, and one out of 80 goats. The parasites were of types found to occur in the intestines of these animals, and they were always rare in the films. The method employed in making the blood films did not entirely exclude the possibility of contamination, but it would have been a remarkable feat for spirochaetes to have reached the slides in this manner without other recognisable intestinal matter accompanying them, and it is certainly just as probable that they had found their way into the blood stream through the intestinal wall.

The intestinal spirochaetes are sometimes present in such enormous numbers that one cannot but suspect that they are not

entirely harmless. In man they are often most abundant in cases of diarrhoea, and they are certainly suspected of being directly connected with this condition. Fantham (1916) has described the act of penetration of epithelial cells in human faeces by spirochaetes, an observation which suggests that they may similarly enter the cells lining the intestinal canal.

Without unduly insisting on this point, it may be suggested that intestinal spirochaetes are at any rate a potential danger, and may be capable of pathological activity, either by spreading into the blood-vessels and producing a generalised infection, or by invading the cells of the intestinal walls, or even by mechanical irritation.

During the last few months, in connexion with some work on *S. eurygyrata*, I have had occasion to examine a few domestic animals, rats, etc., for intestinal spirochaetes, and a short account of the organisms found in them may be of interest. I shall, however, confine myself to a consideration of those forms resembling more or less closely *S. eurygyrata*, the type found in the human intestine.

1. MONKEY

A little more than a year ago, I found great numbers of small spirochaetes in smears made from the large intestine and rectum of a monkey (*Cercopithecus petaurista*) that had died of amoebic dysentery at Accra. In the brief account of these organisms that I published (1915), it was pointed out that their morphology closely resembled that of *Spirochaeta eurygyrata*, and a few individuals were figured in support of this statement.

I have recently re-examined some of the specimens taken from this monkey, and I have been unable to discover any points of distinction between the spirochaetes found in them and those so common in human faeces (fig. V, 1-24). All the organisms in the monkey were of the loosely coiled type, but, as I have pointed out elsewhere (1916), in many human stools, also, only this type is found.

The apparent thickness of this organism, as of all the others of this type, varies according to the stain employed and the method of fixation used. In my earlier account, from dried smears stained by Leishman's method, the spirochaetes were described as being extremely slender, but after re-staining with gentian violet they appeared to be rather thicker, about 0·2μ.

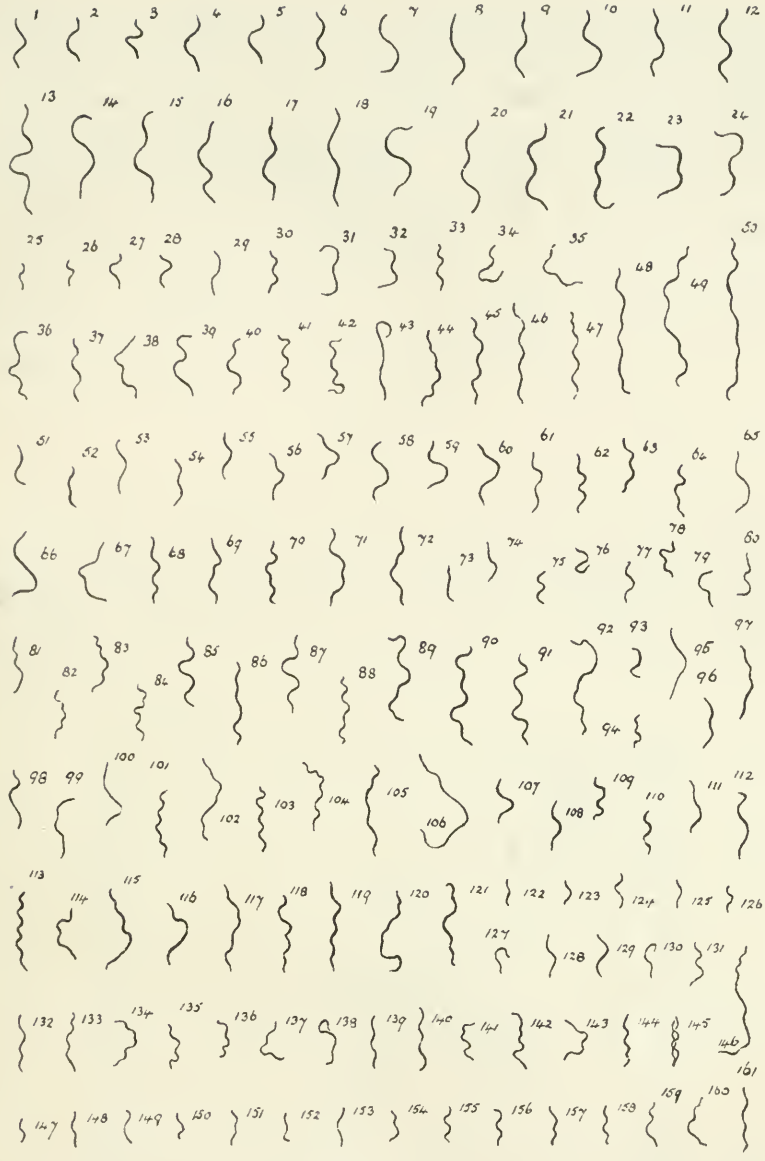

Fig. V.—1-161 : spirochaetes from the faeces of various animals, namely :—1-24, a monkey ; 25-50, rats ; 51-72, sheep ; 73-92, cattle ; 93-106, goats ; 107-121, pigs ; 122-146, dogs ; and 147-161, cats. All the drawings were made with the aid of an Abbé-Zeiss camera lucida. The magnification is × 2000. The thickness of the organisms is, however, only approximately correct.

In my original description the measurements of twenty-five of the spirochaetes were recorded, but as this number was somewhat small, I have re-measured a hundred, taken as they came and drawn with the aid of a camera lucida. Of these hundred spirochaetes, the longest measured 9μ, the shortest 3μ, and the average worked out at 5·42μ (see Table IV). When plotted, these measurements

Table IV.—The measurements of length of the intestinal spirochaetes of man and monkey obtained at autopsies.

Host	Number measured	Lengths in Microns									
		2	3	4	5	6	7	8	9	10	Average
Monkey, at autopsy ...	100	...	3	20	32	26	16	2	1	...	5·42
Man, at autopsy	25	...	...	3	10	5	4	3	...	...	5·76

form a curve similar to that of *S. eurygyrata*, but covering a slightly higher set of figures, the crest of the curve being at 5μ instead of at 4μ (see Chart VI). It must be remembered, however, that the

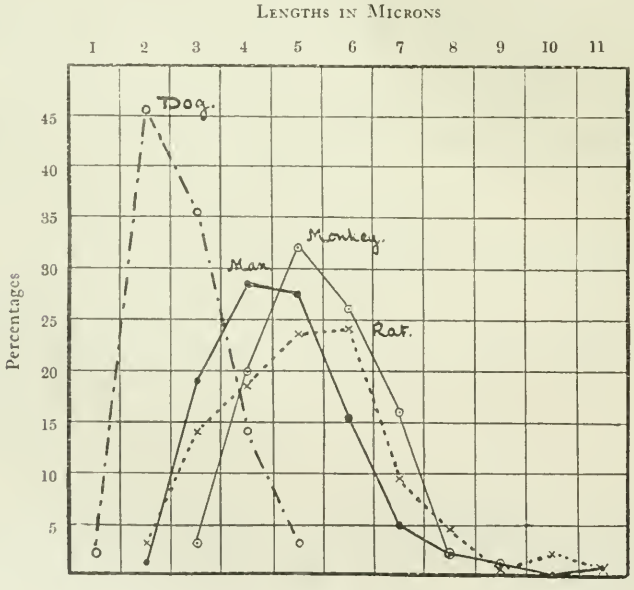

Chart VI.—The distribution, by percentages, of the lengths of the intestinal spirochaetes of man (●—●—), monkey (O·—O——), rats (× - - - × - - -), and dogs (o - — o - —).

specimens were obtained from the monkey after death. Twenty-five spirochaetes were, therefore, measured in a preparation made from the rectal contents of a human subject at an autopsy, these ranged from 4μ to 8μ in length, and averaged 5·7μ (see Table IV). The greatest number, ten, measured 5μ. All the spirochaetes in this preparation were also of the loosely coiled type.

It may be concluded, therefore, that this spirochaete of the monkey was morphologically identical with the human species, *Spirochaeta eurygyrata*, and that the slightly greater average length and the absence of closely coiled individuals was due to changes following the death of the host.

2. RATS

The faeces of a few healthy rats, *Epimys rattus*, have been examined for spirochaetes, and these organisms have been found both in the wild and the albino varieties of these animals. The albino rats had been imported into West Africa about two years previously. The spirochaetes were numerous in some of the animals, scanty in others, but the species of parasite appeared to be the same in each case.

The spirochaetes resembled very closely *S. eurygyrata*, the species found in the human intestine (fig. V, 25-50). They were slender organisms, actively motile by means of lashing, undulatory, and helicoid movements. They varied considerably both in length and breadth and in the number of coils they possessed. Their ends tapered, and were generally sharply pointed. Some of the spirochaetes were loosely coiled, others more closely; some were merely bent like a bow, some showed two or three distinct waves and others five or even more. Recurved forms were occasionally seen, and also small tangles. Indications of both longitudinal and transverse division were observed.

The cytoplasm generally appeared to be homogeneous; but some specimens were banded by rodlets at short intervals along their bodies, and coccoid bodies had formed in others. A distinct membrane was never seen, but the appearance of some of the organisms suggested that it might be present.

The spirochaetes varied a good deal in thickness, but did not

measure more than 0·25μ at their broadest part. The length of the organisms varied from 2μ to 11μ, and averaged 5·27μ in the two hundred individuals measured.

From this brief description it will be concluded that the spirochaete could not be distinguished from *S. eurygyrata* by morphological characters, and as Fantham (1916) has recently published an admirable account of the latter organism, it will be unnecessary to enter into greater detail. The general characters of the spirochaete are, however, indicated in the rough drawings (fig. V, 25-50), and in Table V some details of the measurements of

Table V.—The measurements of length of the spirochaetes found in the intestines of man, rats, and dogs at Accra.

Host	Number measured	Lengths in Microns											
		1	2	3	4	5	6	7	8	9	10	11	Average
Man	200	...	2	38	57	55	31	10	4	2	...	1	4·69
Rat	200	...	6	28	37	47	48	19	9	1	4	1	5·27
Dog	200	4	91	71	28	6	...	...	...	...	...	...	2·70

length are given for comparison with those of the human species. It should be mentioned, however, that I did not observe the spirochaetes penetrating shed epithelial cells and forming coccoid bodies in them as Fantham did in the case of *S. eurygyrata*.

Two hundred spirochaetes from the rats' faeces, taken as they came, were drawn with the aid of a camera lucida and measured (see Table V). They varied in length from 2μ to 11μ, but the longer individuals were rare, and were often obviously dividing forms composed of two daughter spirochaetes joined end to end by a delicate filament (fig. V, 48-50). The single organism, measuring 11μ, appeared to be composed of three parts, measuring 4μ, 4μ, and 3μ, respectively. A much better idea of the length of the spirochaete is obtained by distributing the measurements and plotting them as a curve (see Chart VI); and it is then seen that 80 per cent. of them were within four microns of each other in length from 3μ to 6μ.

On comparing the curves formed by distributing, according to length, two hundred spirochaetes from the faeces of rats and a

similar number from the human stools, they are found to be much alike. In the case of the rat spirochaete the crest of the curve is at 5μ to 6μ, in the case of the human parasite at 4μ to 5μ; but in both curves the great majority of the organisms measured from 3μ to 6μ—80 per cent. of the former, and 90·5 per cent. of the latter. The range of variation in length was also practically identical.

The spirochaete found in the rats' intestine resembled *S. eurygyrata*, Werner emend. Fantham, so closely both in structure and detailed measurements that it would be impossible to distinguish the two organisms by morphological characters, and it is at any rate possible, although one hesitates to make the assertion without further evidence, that they may be the same species.

3. SHEEP, CATTLE, GOATS, AND PIGS

A few sheep, cattle, goats, and pigs have also been examined, and in all of these spirochaetes of the type under consideration have been found in the alimentary canal and in the faeces. The parasites appeared to be identical in all these animals, and they were indistinguishable, both when alive and after fixation and staining, from the organisms found in rats and man. The brief description of the rat spirochaetes given above may be read word for word as applying to these organisms, and the rough drawings (fig. V, 51-121) will serve to illustrate the morphological similarity.

Twenty-five spirochaetes, taken as they came from each species of animal, were drawn with the aid of a camera lucida and measured (see Table VI). The average length was 4·7μ in sheep,

Table VI.—The measurements of length of the intestinal spirochaetes of various animals examined at Accra.

Host	Number measured	Lengths in Microns										
		1	2	3	4	5	6	7	8	9	10	Average
Sheep	25	...	...	3	7	11	3	1	...	...	...	4·7
Cattle	25	...	...	8	7	2	3	2	3	...	...	4·7
Goat	25	...	...	3	3	8	5	4	1	...	1	5·5
Pig	25	...	...	3	6	6	6	2	...	2	...	5·2
Cat	25	1	11	9	4	...	...	...	...	...	...	2·4

4·7μ in cattle, 5·5μ in goats, and 5·2μ in pigs. Considering the small number of measurements made in each case, the lengths correspond fairly closely with each other and with those of the rat spirochaetes and *S. eurygyrata*.

A series of smears from various parts of the alimentary tract of one sheep were examined, and in them spirochaetes of this type were found in the specimens from the stomach, as well as in those from the intestine.

It may be mentioned that the majority of the spirochaetes found in blood films from the Accra slaughter-house (1914), to which reference has been made, were of the same type. The measurements and illustrations given in the Report of the Accra Laboratory for the year 1914 clearly show this. It is possible, therefore, that under certain conditions the organisms may find their way from the intestine into the blood stream, in which case they would have to be distinguished from *S. theileri*, the parasite found by Theiler in cattle suffering from a disease characterised by fever, diarrhoea, and splenic enlargement, which is a much longer organism, measuring 20μ to 30μ in length.

4. DOGS

In the faeces of an apparently healthy rough-haired terrier of European extraction an exceedingly heavy infection with minute spirochaetes was found (fig. V, 122-146). The dog had lived for a long time in West Africa and was thoroughly acclimatised, and at the time of examination did not appear to be suffering from any pathological condition. The same organism has also been found in two native dogs; the infection in one being very heavy and in the other slight. A third native dog examined did not appear to harbour any spirochaetes.

The living spirochaetes were active, but their movements did not show any characteristics of specific importance. They were very small, and in consequence structural details were difficult to observe. When fixed and stained the spirochaetes were seen to be delicate organisms of varying size, with flexible bodies bent into an inconstant number of waves. Their ends were tapering and generally sharply pointed, but the shorter and thicker individuals had somewhat blunter extremities. The body was as a rule loosely,

but sometimes closely coiled, and the number of separate waves varied greatly. Some specimens were bent into a simple bow, others showed four or even more closely set waves, but the majority had one or two relatively loose coils. A few tangles were found in the films.

The cytoplasm of most of the spirochaetes appeared to be homogeneous, but a few were definitely banded by chromatinic rodlets. Coccoid bodies were frequently visible. The membrane, if it was present, was indistinguishable, but the organisms were so small that this structure could scarcely have been visible under any circumstances. Spirochaetes in process of transverse fission were frequently seen, and a few multiple forms were present. Other organisms were observed which appeared to be undergoing longitudinal division.

Although the spirochaetes were abundant in all parts of the faeces, they were most numerous in the mucus contained in it. The cells in the excrement did not appear to have been invaded by the parasites, and the small number of spirochaetes that looked as if they were within them may really have been lying on their surfaces. No definite evidence of an intracellular phase could be discovered.

The spirochaetes were slender organisms, but varied considerably in thickness. The smaller individuals were relatively the stouter. Accurate measurements were, of course, impossible, but even the thicker ones were less than $0{\cdot}25\mu$ broad.

The length of the parasite was determined by drawing two hundred individuals, taken as they came, with the aid of a camera lucida, and measuring them. The shortest length was 1μ, the longest 5μ, and the average worked out at $2{\cdot}7\mu$ (see Table V). The great majority of the spirochaetes, 81 per cent., measured 2μ to 3μ (see Chart VI). Elsewhere in the films a very few longer organisms were found, some of which reached 9μ (fig. V, 146). These were apparently multiple forms. The infected animals were examined on several occasions at intervals of a week or ten days without observing any morphological changes suggesting that these small spirochaetes were a stage in the development of a larger organism. In general character the spirochaete approximated to the *S. eurygyrata* type, but a comparison of the curves made by plotting the measurements of length of the two organisms shows clearly that they were not

identical. The spirochaete found in the dogs was a much smaller organism with a more restricted range of variation.

Various spirochaetes have previously been described as occurring in the alimentary canal of dogs by Oppenheimer, Bizzozero, Salomon, and Rigaud. I have not been able to consult the works of these authors in the originals, but, according to Bosanquet, the organisms discovered by Bizzozero lay within vacuoles in the epithelial cells, showed three to seven coils, and measured 3μ to 8μ in length, and may have been the same as those found by Oppenheimer. Salomon's spirilla were longer and had terminal flagella, and the organisms found by Rigaud resembled *T. pallidum*. The spirochaete I have described above resembled none of these organisms. Balfour (1906) discovered spirochaetes in the stomach and intestines of dogs dying of experimental trypanosomiasis in the Sudan, and eight specimens from a gastric ulcer are figured in a beautiful coloured plate (XIV) in the Second Report of the Wellcome Research Laboratories, Khartoum. They appear to have been thicker and much more closely and regularly coiled organisms than those I have described; and, judging from the individuals figured, longer (6μ to over 10μ). I have found what I believe to be this species of (?) spirochaete in the stomachs of dogs and a cat (see p. 341), and if I am correct in the identification, it is an entirely different parasite.

For descriptive purposes it will be convenient to name the spirochaete found in the dogs at Accra, and I, therefore, propose that it should be called *Spirochaeta canis*.

5. CATS

The faeces of four cats have been examined, and in three a few, but only a few small spirochaetes were found. The organisms appeared to be identical with those found in dogs (*S. canis* n. sp.), a description of which has already been given (fig. V, 147-161).

Twenty-five individuals, taken as they came and drawn with the aid of a camera lucida, measured from 1μ to 4μ, but averaged 2·4μ in length (see Table VI). Twenty of the twenty-five measured 2μ to 3μ. The general form of the spirochaete is shown in fig. V, and it will be seen that it exactly resembles that of the organism found in the dog.

These three cats were obtained from the house of a native.

In the fourth cat two distinct spiral organisms were found, the one in the stomach and the other in the large intestine and rectum. This animal was examined only after death, its body having been sent to the laboratory for dissection by its European owner.

The organism found in the stomach was not of the *Spirochaeta eurygyrata* type, so that it does not properly concern us here. It was, however, a relatively thick organism, so closely coiled that it resembled a screw with a narrow thread (fig. VI, 1 and 2). The ends

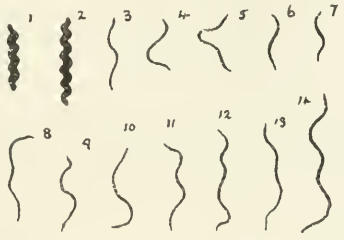

Fig. VI.—1 and 2: spiral organisms from the stomach; and 3-14: spirochaetes resembling *S. eurygyrata* from the large intestine and rectum of a cat examined after death. All the figures were drawn with the aid of an Abbé-Zeiss camera lucida at a magnification of 2000 diameters.

of the parasite were really blunt, but as they were parts of incomplete coils they stood out slightly, giving the appearance of pointed extremities to the whole organism. The actual breadth of the parasite was about 0·4μ or 0·5μ, but the body was coiled so closely and so evenly that the apparent breadth was really the diameter of the spiral, and this was about 0·8μ. The diameter of the spiral was constant from end to end of the organism, and did not vary in different individuals. The length of the body varied considerably, but could not be measured owing to the closeness of its coils; but some idea of the range may be gathered from measurements of the axial length. With the aid of a camera lucida, the axes of twenty-five individuals, taken as they came, were drawn. They ranged in length from 3μ to 8μ, and the average was 5·48μ (see Table VII). In the same individuals the number of coils varied from 3 to 10, and averaged 5·9. The coils appeared to be fixed. This organism was, I think, the same as that found by Balfour in the stomach of a dog, and figured in the Second Report of the Wellcome

Research Laboratories, Khartoum, and should probably be referred to the genus *Treponema*.

Table VII.—The lengths in microns and the number of coils of twenty-five individuals of a spiral organism found in the stomach of a cat.

Morphological feature	Lengths in Microns or the Number of Coils							
	3	4	5	6	7	8	9	10
Lengths in microns	1	4	7	7	5	1	...	...
Coils	1	6	6	5	3	1	1	2

In the large intestine and the rectum of the same cat a great number of small spirochaetes were found. These were delicate organisms with pointed extremities, morphologically indistinguishable from *S. eurygyrata* (fig. VI, 3-14). It will be unnecessary to give a detailed description of these spirochaetes, as already the type has been considered more than once in this article, and the description already given may be re-applied here. They were all loosely coiled in this cat, but a similar absence of closely coiled specimens was observed in *S. eurygyrata* obtained from the human subject after death, and in the case of the monkey already referred to. A hundred individuals, taken as they came, were drawn with the aid of a camera lucida, and measured. They ranged from 3μ to 11μ, and averaged $5{\cdot}78\mu$ in length. When distributed according to their lengths it was found that 86 per cent. of them measured within four microns of each other in length between 4μ and 7μ (see Table VIII). These measurements of length are almost identical

Table VIII.—The measurements of length of a spirochaete found in the large intestine and rectum of a cat.

Host and Habitat	Number measured	Lengths in Microns								
		3	4	5	6	7	8	9	10	11
Cat, large intestine and rectum	100	3	13	33	23	17	7	2	1	1

with those of the spirochaete found in the large intestine of a monkey which had died of dysentery, and it must be concluded that this organism also was morphologically identical with *S. eurygyrata*.

CONCLUSIONS

1. Spirochaetes of the *S. eurygyrata* type have been found in the faeces of certain of the lower animals examined at Accra.

2. The first type was found in a monkey, a cat, rats, sheep, cattle, goats, and pigs, and appeared to be morphologically indistinguishable from *S. eurygyrata*, the species found in man.

3. The second type, for which the name *S. canis* is proposed, was found in dogs and cats. This was a smaller organism, measuring most commonly 2μ to 3μ in length, and about $0{\cdot}2\mu$ in breadth.

REFERENCES

Bosanquet, W. C. (1911). Spirochaetes, p. 115. W. B. Saunders Company, Philadelphia and London.

Fantham, H. B. (1916). Observations on *Spirochaeta eurygyrata*, as found in Human Faeces. *Brit. Med. Journ.*, 2893, pp. 815-816.

Macfie, J. W. S. (1915). *Report of the Accra Laboratory for the year* 1914, pp. 32-33, and Plate I. J. & A. Churchill, London.

—— (1915). A Case of Dysentery in a Monkey. *Annals of Trop. Med. & Parasitol.*, Vol. IX, pp. 510-511.